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Crystal Barker Schaaf, Xiaowen Li*, Alan H. Strahler*

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Phillips Lab/GPAA
Hanscom AFB
Massachusetts 01731-5000

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EFFECTS OF SOLAR ZENITH ANGLE ON FOREST CANOPY ALBEDOS CALCULATED WITH A GEOMETRIC-OPTICAL MODEL

Crystal Barker Schaaf[1,2], Xiaowen Li[2], Alan H. Strahler[2]

[1]Geophysics Directorate
Philips Lab
Hanscom AFB, MA 01731

[2]Center for Remote Sensing
725 Commonwealth Ave
Boston, MA 02215

ABSTRACT

The Bidirectional Reflectance Distribution Function (BRDF) provided by the Li-Strahler geometric-optical forest canopy model has been integrated to provide instantaneous hemispherical reflectances of vegetated surfaces. Given the anisotropy of canopied surfaces, the sensitivity of these spectral albedos to the illumination angle of the sun was suspect and therefore required testing. A variety of simulated canopies (conifer, savanna and shrub) were modeled with varying solar angles. In all cases, the surface albedo gradually decreased with increasing solar zenith angle. Such insensitivity to solar position simplifies the realistic modeling of surface albedos for energy balance studies.

Keywords: Hemispherical reflectance; surface albedo, directional reflectance; BRDF.

INTRODUCTION

Complex, three-dimensional surface covers such as forests and woodlands are known to exhibit highly anisotropic reflectances, due, in part, to such effects as self-shadowing and specular reflectance. This implies that spectral albedo, taken as the integral of the spectral BRDF over the hemisphere for a given sun position, might be quite dependent on sun position. The Li-Strahler forest canopy model [1] [2] [3] [4] accounts for the anisotropic behavior of the BRDF using geometric optics and simple principles of Boolean set theory, and provides the opportunity to explore the diurnal variation of spectral albedo. The model views a scene as an assemblage of illuminated tree crowns of ellipsoidal shape. The reflectance of the areal components of shadowed and sunlit canopy and shadowed and sunlit background as seen from a given view direction determine the directional reflectance for a given illumination angle. The effects of the mutual shadowing and obscuring of tree crowns by one another are included. This directional reflectance model has been extended to provide instantaneous surface albedo computations of discontinuous vegetated canopies. As the model produces a reflectance for each small change in viewing angle, surface albedo for a particular solar illumination angle can be calculated by the numerical integration of the directional reflectance over the viewing hemisphere. At present, this hemispherical reflectance represents a direct beam, spectrally-dependent value which does not include multiple scattering, diffuse or specular effects.

SENSITIVITY TEST RESULTS

The sensitivity of the surface albedo calculation to solar illumination angle was explored in a series of model runs using realistic solar zenith angles for the summer solstice at the latitude of Boston, MA. These systematic tests simulated several canopies including high and low coverage of conifer forest (simulated as tall, thin ellipsoids 10 m wide and 20 m tall on 10 m trunks), savanna (sparse, flat ellipsoids 10 m wide and 5 m tall on tall 10 m trunks), and shrubland (ellipsoids 0.5 m wide and 1 m tall sitting on the ground). Since the contrast between dark canopy and bright background in red wavelength images is the reverse of that in infrared scenes (with brighter canopies and darker backgrounds), scenarios using both red and infrared areal component reflectances were evaluated.

The BRDFs of the various surfaces display similar general features at any given solar angle (Figures 1a-c). The hotspot peak occurs when the viewing position approaches the illumination angle. Its shape is governed by the brightness contrast between tree crown and background and by the shape and density of the crowns and the rapidity with which the shadows they cast are revealed when the viewing and illumination geometry diverge. Opposite the hotspot, increasingly large areas of shadow (with lower reflectances) are viewed. An upturned bowl-shape is produced when the proportion of viewed shadows is reduced by the obscuring of the shadows by the crowns themselves (i.e., the scene brightens at the bowl edge as only unshadowed crown tops are viewed). This occurs at either high illumination or high viewing zenith angle (or both) and only for those crown shapes that present a larger cross section at higher zenith angles (tall thinner shapes).

As solar illumination progresses from noon to late afternoon the position of the hotspot, of course, changes correspondingly. Beyond the hotspot region of the BRDF, larger and more elliptical shadows occur and darken the scene as the solar zenith angles increases (at least until large solar and viewing angles are reached, where the mutual shadowing effects start to occur).

Intuitively, therefore, one would expect the geometric-optical model to produce an increasing area of shadowed surface as illumination angle increases, producing a decreasing trend in the integrated value which represents the surface albedo. And this is indeed the case in all the simulations tested. The instantaneous hemispherical reflectance consistently decreases in a gradual manner as the solar zenith angle increased (Figures 2-7). Although the amount of shadowed area may be somewhat lessened by the mutual shadowing effects of a crown illuminated by large solar zenith angles, the overall surface albedo does not reflect this effect.

Eaton and Dirmhirn, [5] using a pyranometer, record similar behavior for a number of naturally and agriculturally vegetated covers. Kimes and Sellers, [6] using large numbers of field measured directional reflectances to calculate the hemispherical reflectance, also obtain gradually decreasing albedo values as a function of increasing solar zenith angle for cover types such as orchard grass, steppe grass and corn. These values are not of forested scenes, yet the coverages in these particular cases are sparse and background shadowing occurs (lending themselves to geometric optical modeling). However, the published albedo values of other vegetated surfaces (usually of dense crops or grasses) suggest that surface albedo increases with solar zenith angle [6], [7]. These higher values are primarily attributed to specular effects, which are enhanced by a glancing sun angle. Eaton and Dirmhirn [7] also discuss the role of specular reflection in some of their measurements. Specular effects are not addressed in the present form of the Li-Strahler model.

CONCLUSIONS

Instantaneous and daily surface albedos are required for surface energy budget models and local climate models. Since a forest canopy is intrinsically anisotropic, the use of a single nadir reflectance measurement is not sufficient to estimate the instantaneous surface albedo. However, the directional reflectances of a geometric-optical model can be integrated to generate hemispherical reflectances for given illumination angles, canopy characteristics and spectral signatures. Such an albedo calculation has been shown to have a consistent, gradually decreasing relationship with solar zenith angle, simplifying the calculation of a daily quantity. The fact that hemispherical reflectance does not seem to be overly sensitive to changes in sun position throughout the day bodes well for the use of simple models in studies of surface energy balance and ecological energetics for complex vegetation covers.

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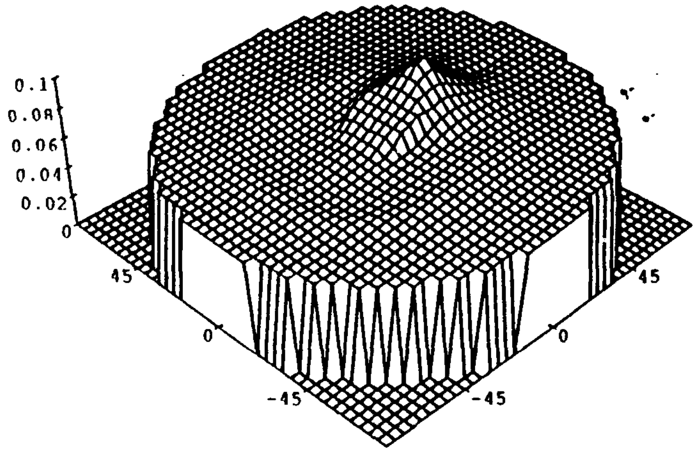

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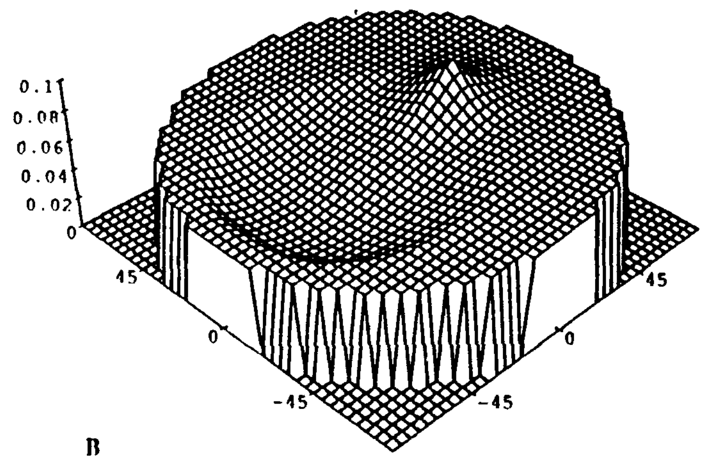

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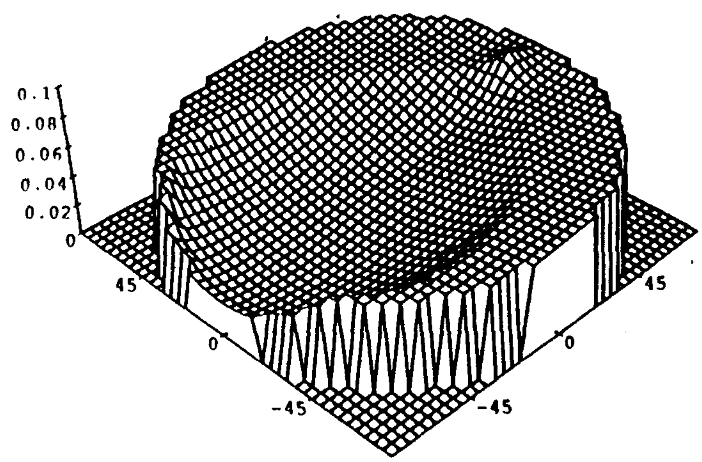
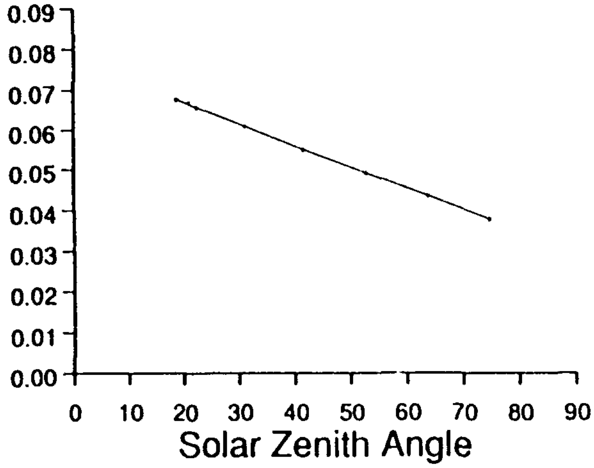


Figure 1. The modeled BRDF of a 60% conifer covered surface (red wavelength) for three solar zenith angles; (a) 18.5 °, (b) 31.0°, and (c) 63.7°.



igure 2. The modeled instantaneous surface albedo for a 60% ›nifer covered scene (red wavelength).

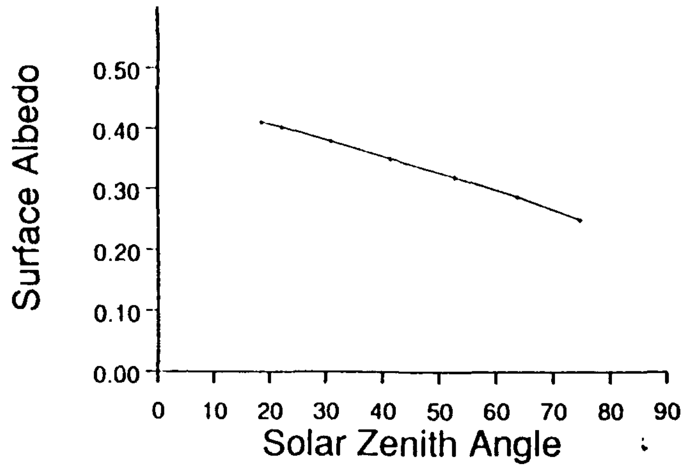
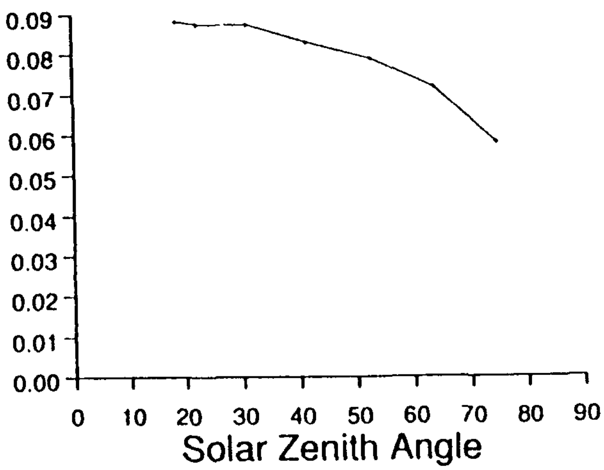


Figure 3. The modeled instantaneous surface albedo for a 60% conifer covered scene (infrared wavelength).



ȝure 4. The modeled instantaneous surface albedo for a 40% vanna covered scene (red wavelength).

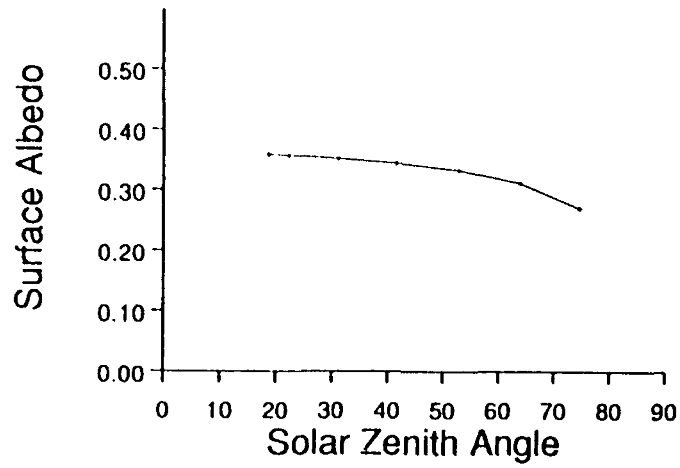
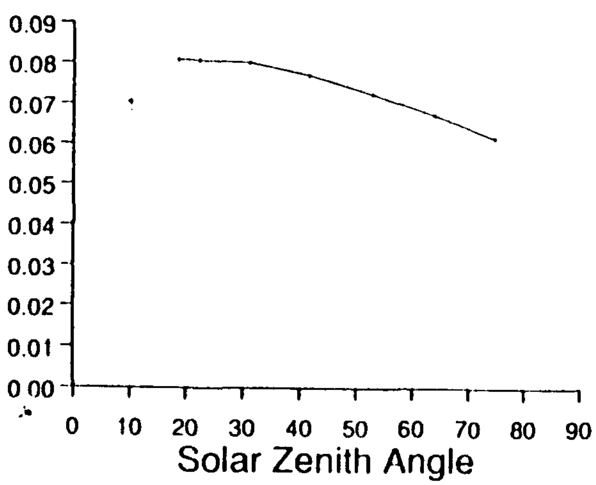


Figure 5. The modeled instantaneous surface albedo for a 40% savanna covered scene (infrared wavelength).



'igure 6. The modeled instantaneous surface albedo for a 80% ›hrub covered scene (red wavelength).

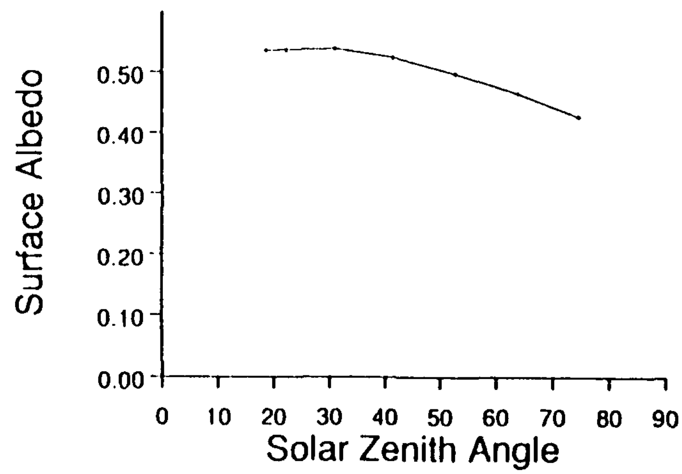


Figure 7. The modeled instantaneous surface albedo for a 80% shrub covered scene (infrared wavelength).